E7.6-10210

NASA CR-
147475

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FINAL SKYLAB EREP REPORT

- TASKS 505801, 505802, 505804 -

EPN-008
2/12/76

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DCAF# 002583

Initial proposed themes

The proposal, from the french Météorologie Nationale, for participation in SKYLAB EREP Experiment was formally adopted by NASA, in October 1972 (Letter SR 008, dated October 6, 1972).

The proposal included three themes :

The theme N° 1 followed the lines of a current scientific project, lead by french meteorologists, investigating mesoscale cloud features physical mechanisms, and using photographs taken by constant level high altitude balloons, simultaneously with thermodynamic and kinematic informations given by an associated ground network.

Its main goal was to improve a model describing the physical relationship between the convective cloud rows and the wind profiles, and to check its rehability.

The theme N°2 used the former demonstration that microwave attenuation and diffusion through clouds could give information about the water content in cloud depth. It had seemed possible to infer, from such radiometric data, the occurence of precipitation under clouds over the ocean. EREP data would give an opportunity to check the mathematical model rehability.

The theme N° 3 wanted to determine the snow cover, its temperature, the beginning of the melting and to research statistical relations between superficial characteristics of the

(E76-10210) THE POSSIBILITY OF EVALUATING VERTICAL WIND PROFILES FROM SATELLITE DATA Final Report (Centre National d'Etudes Spatiales) 42 p HC $4.00 CSCL 04B

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snow and its spectral signature.

Proposed associated experiments

Theme N° 1

There would have been a joint experiment conceived as follows : EREP would give a detailed picture of cloudiness, both by its photographic facility S 190, and its IR sensor S 192, operating in the 10 to 12,5 micrometer atmospheric window, over south-west of FRANCE. Simultaneously, according to satellite ephemeris, a very dense ground network of radiowind, radiosonde and radar stations, specially settled in the same region, and supplemented by three specially equipped aircrafts, would operate and give information on the thermodynamic and kinematic structure of the observed air mass (fig. 1,2,3).

Theme N° 2

The experiment would make use of EREP data, CCT, at various times of the same part of the Atlantic Ocean, for various meteorological situations, without cloud, with thin or thick precipitation. A special mode of operation, for S 193, was asked and accepted. The ocean temperature would be simultaneously checked by NIMBUS HRIR measurements. The cloud droplets distribution could be obtained by in situ mesurements;twenty-five flight hours of a french Navy plane "NEPTUNE" were scheduled for this purpose (fig. 4).

Theme N° 3

Ground mesurements of snow state and temperature were foreseen, simultaneously with SKYLAB S 192 data (fig. 5).

How the experiments worked

Theme N° 1

The choosen date for the experiment was September 17, 1973

A very important ground and air network was in position, including 12 complete radio sounding stations, 2 radar stations, 1 plane used for upper air measurements and 2 high altitude MIRAGE IV planes were used for taking pictures of nebulosity along one choosen orbit path. The track displacement of 2°46' East made this network completely useless.

Theme N° 2

The experiment, which was scheduled for September 1973 (SL 3), had to be cancelled, because of an ill-functioning of the S 193 SKYLAB apparatus.

Theme N° 3

The experiment, which was scheduled for the end of May 1973, had to be cancelled, because of the slippage of the SKYLAB II launching and the actual fact that the snow melting is to be completed by mid-June over the french ALPES.

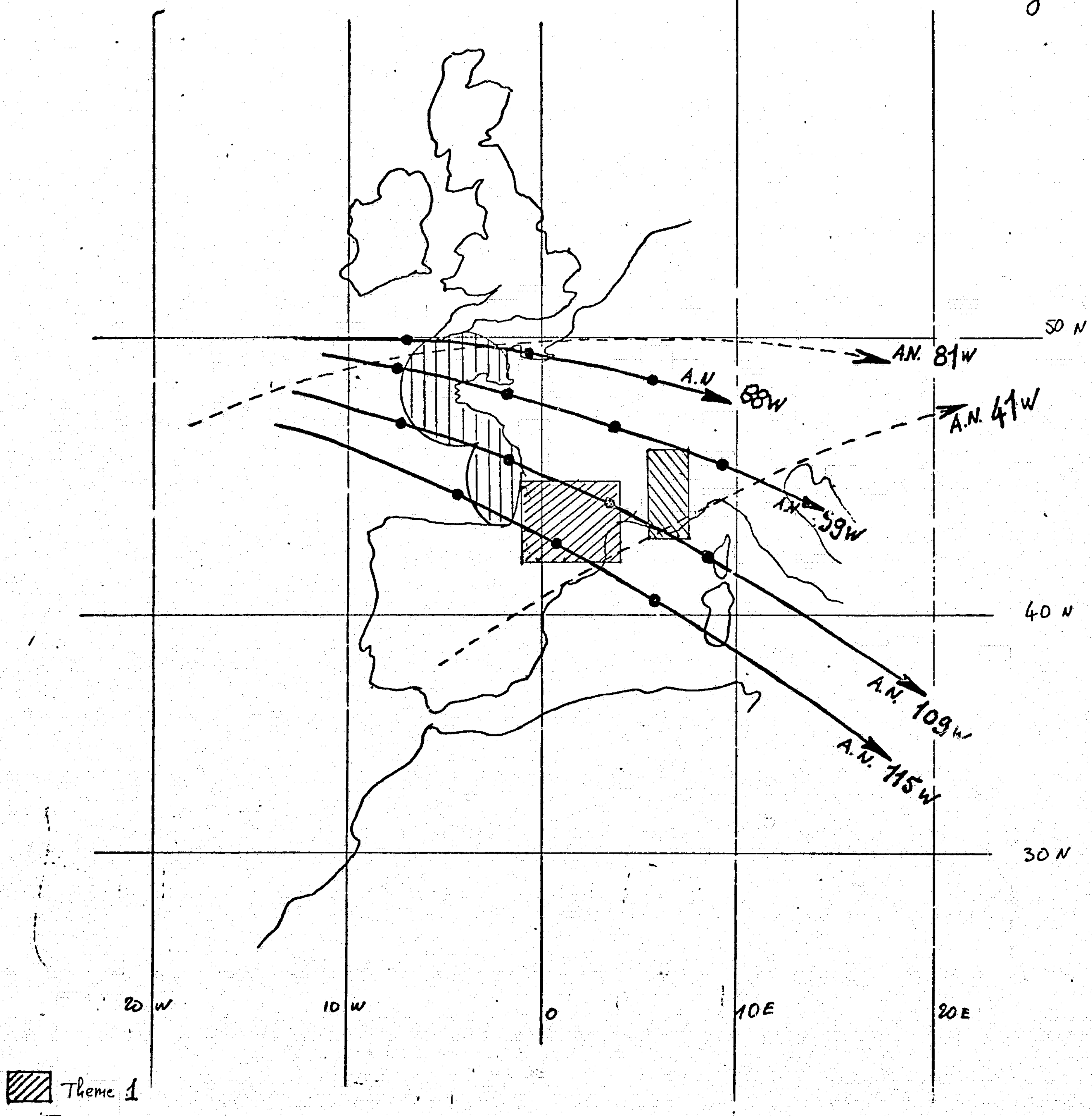
Final results

As we just said, there were no result for experiment 505802 and 505804, which had to be cancelled, and for the first experiment, the experiment 505801, there was also no result for the choosen date of September 17.

But, as it is mentionned above, the main goal of the theme N° 1 was to check and to improve a model describing the physical relationship between the convective cloud rows and some thermodynamic parameters. Without a special network, it has been possible, for this purpose, to work on a very interesting cloud streets pictures, taken over FRANCE, by SKYLAB S 190, the 19th of September 1973.

The result of this work, a document about "The possibility of evaluating wind profiles from satellite data" was sent to you March 24, 1975. I should appreciate if we could receive some kind of appreciation or criticism about this paper.

Fig. 1



A.N. = Ascending Node
The dots along the tracks are time markers (every minute)

Meteorologie Nationale - SKYLAB participation
Test zones and selected orbits

EXPERIENCE SKYLAB PYRENEES-AQUITAINE

ETUDE DE LA CONVECTION

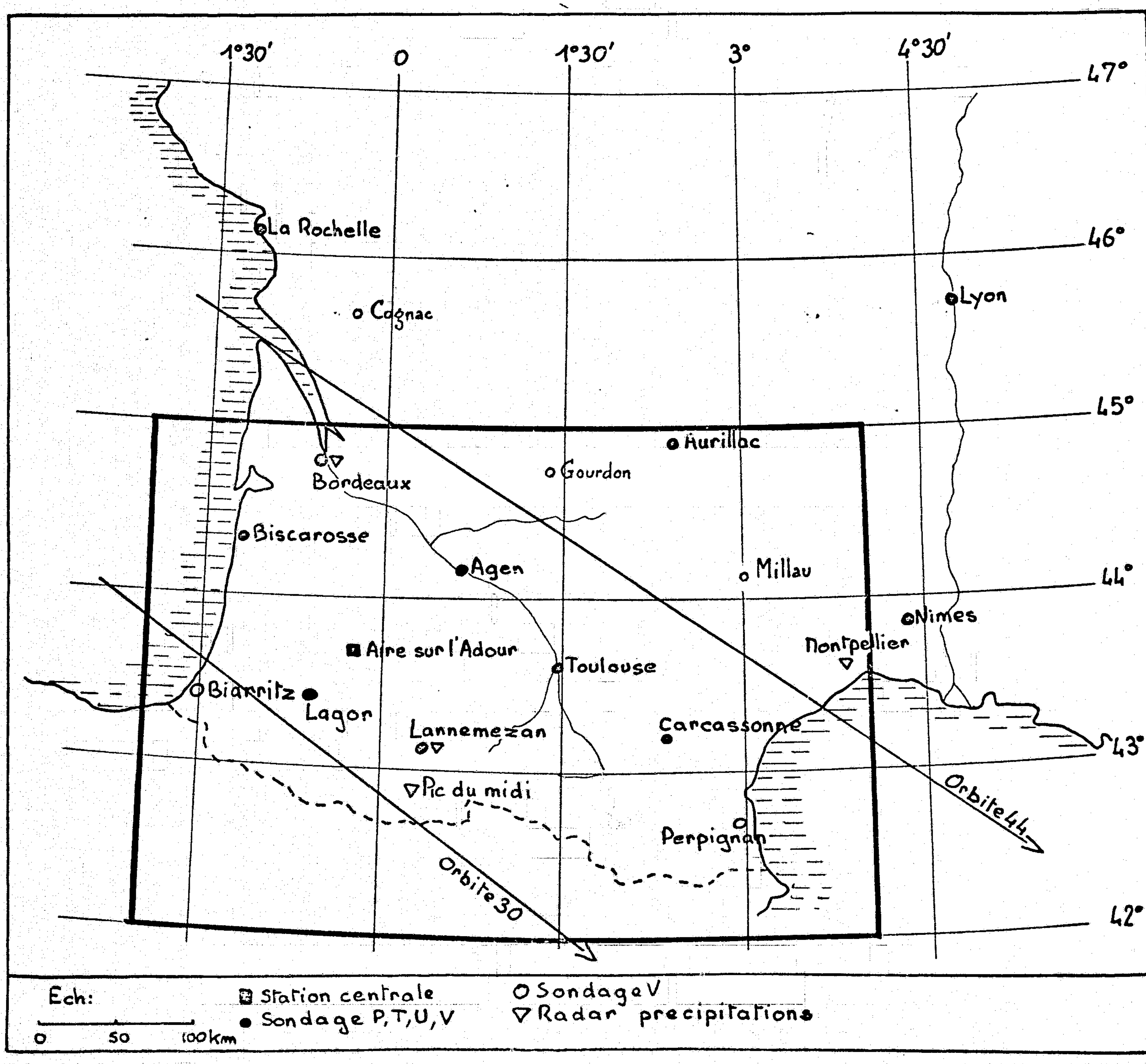
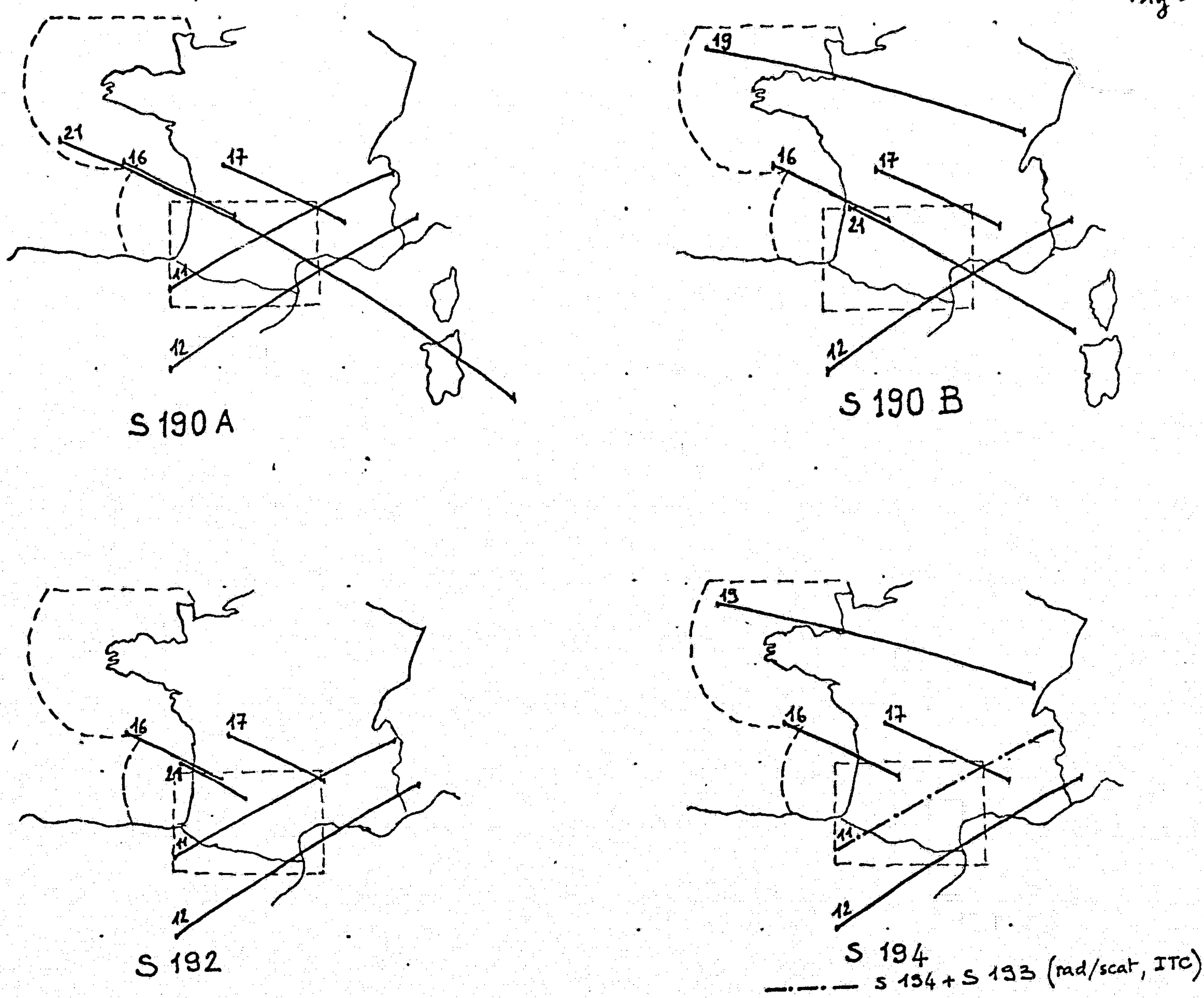


Fig 2

Fig 3



Données acquises par SKYLAB
au cours du mois de Septembre 1973
Le quantième du mois est indiqué au début de chaque trace

Fig 4

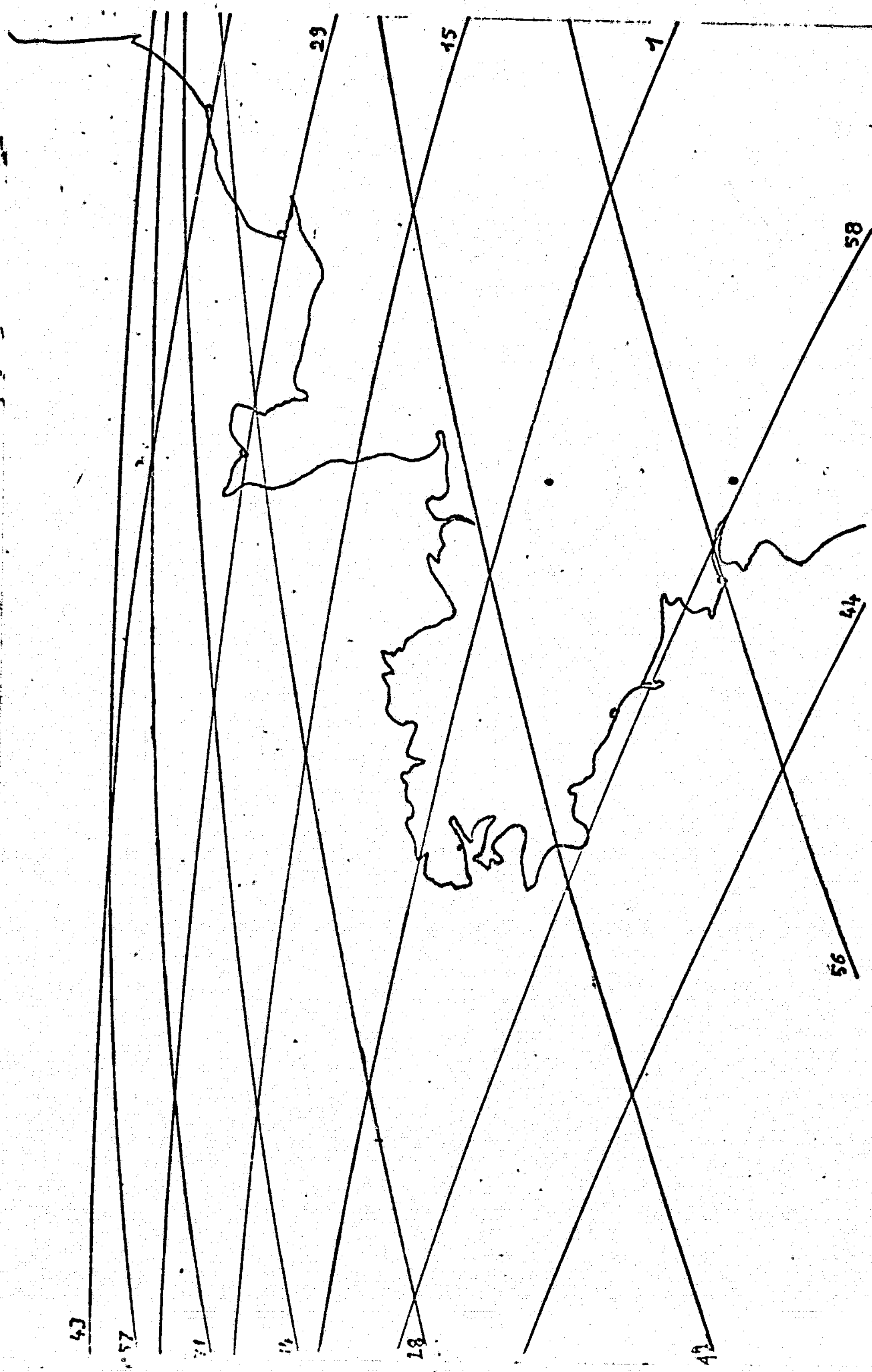
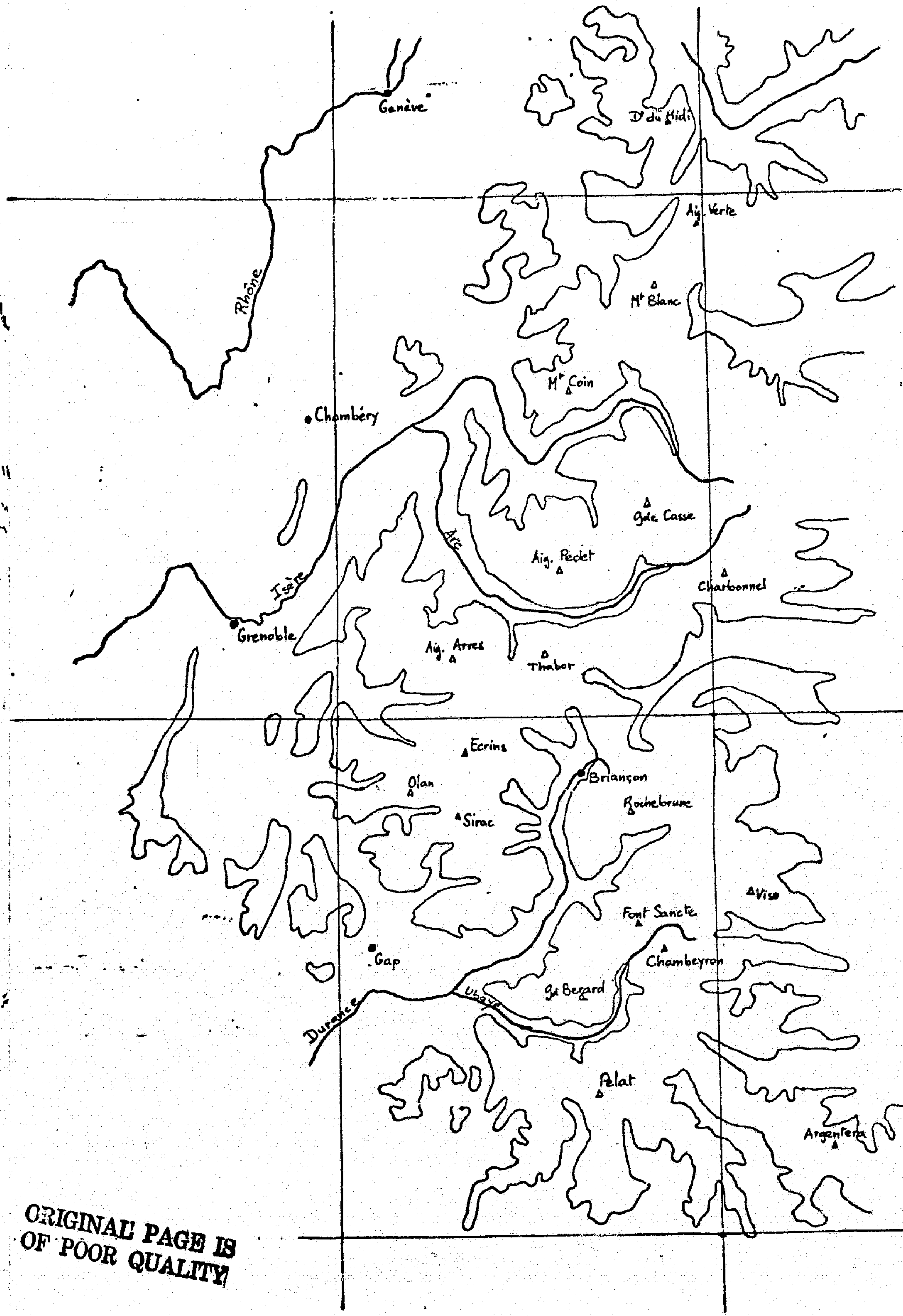


Fig 5



Genève
Rhône
Dt du Midi
Aig. Verte
Mt Blanc
Mt Coin
Chambéry
Gde Casse
Arc
Aig. Peclet
Isère
Charbonnel
Grenoble
Aig. Arves
Thabor
Ecrins
Briançon
Olan
Rochebrune
Sirac
Viso
Font Sancte
Gap
Chambeyron
Gd Bérard
Ubaye
Durance
Pelat
Argentera

8

PARTICIPATION IN THE SKYLAB PROGRAM

The possibility of evaluating vertical wind profiles from satellite data

A.R. WEILLER

ABSTRACT

In the presence of convective movements, a method is proposed for evaluating the vertical variation of the horizontal wind. The profile is determined from the following data: on the one hand, the wind and the air temperature at the upper and lower boundaries of the convective layer; on the other hand, the value of a so-called characteristic dimension enabling the determination of three wavelengths which define the general morphology of the convective cell.

The author, after discussing the establishment of the vertical wind equation, proposes a sinusoidal solution for it, which is appropriate to the phenomenon investigated. This solution requires a clearly defined profile of the horizontal wind. The morphology of the cell is derived from its characteristic dimension by a minimization of the internal dissipation of friction energy, the calculation being made for six types of cell. The author provides details concerning the numeric analytical methods employed and supplies a general calculation flowchart. Finally, tables are presented covering widely varying regions, corresponding either to cloudstreets or to cells, depending on the vertical thermal gradient and the value of the characteristic dimension.

This method was developed during an in-flight experiment on Skylab III, which permitted accurate measurements of a cloudstreet observed over France. A comparison was made of the profile calculated by this method and that measured by the nearest wind sounding.

As a consequence of the initial satisfactory results thus obtained, the author proposes to systematically check this method on a sufficient number of radiosoundings, the thickness of the convective layer being taken as the characteristic dimension of the convective cell. Subsequently, should the results prove satisfactory, the method may be applied to satellite pictures of cloudstreets, taking the inter-street spacing as the characteristic dimension, and calculating the thermal gradient as a function of the service temperatures supplied by the V.H.R.R.

1. VERTICAL WIND EQUATION

Throughout this study, the symbols employed by J.P. Kuettner in his article published in 1971 (1) will be employed as far as possible.

It is worthwhile starting with an initial reminder of the establishment of the vertical wind equation. In the initial stage, the turbulent viscosity and conductivity coefficients are ignored. The basic equations, reflecting a situation of stationary state convection, can be written as follows:

$$
\begin{aligned}
u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} &= - \frac{1}{\rho} \frac{\partial p}{\partial x} \\
u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} &= - \frac{1}{\rho} \frac{\partial p}{\partial y} \\
u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} &= - \frac{1}{\rho} \frac{\partial p}{\partial z} - g \\
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} &= 0 \\
u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} &= - \gamma_a w
\end{aligned}
\qquad (1)
$$

with $g = \left| \vec{g} \right|$

Although this model of equation is generally acceptable for this type of problem, it is worthwhile elucidating some of its underlying hypotheses.

.No account is taken of the Coriolis force, which is negligible at the scale of circulation of convection with respect to the local horizontal pressure gradient. The continuity equation is represented by non-divergence of the wind vector. This implies an acceptance of Boussinesq's so-called incompressibility hypothesis. This approximation postulates that at a given level, the density of the air varies only with temperature.

By giving ∇ A, and to the symbols $A, \overline{A}, A', A''$, the same relative meanings as Kuettner (1), A representing the perturbation term and A' the first derivative with respect to z, we have the following equivalents:

$$\frac{\delta}{\delta t} = \overline{w} = \frac{\delta}{\delta x}\left(\overline{u},\overline{v},\overline{p},\overline{\rho},\overline{T}\right) = \frac{\delta}{\delta y}\left(\overline{u},\overline{v},\overline{p},\overline{\rho},\overline{T}\right) = 0$$

Hence:

$$g = -\frac{1}{\overline{\rho}}\frac{\delta\overline{p}}{\delta z}$$

and, in accordance with Boussinesq's approximation,

$$\frac{\rho}{\overline{\rho}} = -\frac{T}{\overline{T}}$$

In these conditions, by employing the operator h, such that

$$h(\ ) = \overline{u}\frac{\delta(\ )}{\delta x} + \overline{v}\frac{\delta(\ )}{\delta y}$$

and by linearizing, namely, ignoring the minor terms of the type $u\frac{\partial u}{\partial x}$ or $\frac{1}{\overline{\rho}}\frac{T}{\overline{T}} + \frac{\delta p}{\delta x}$

the initial system can be written:

$$h\ (u) + \overline{u}'w = -\frac{1}{\overline{\rho}}\frac{\delta p}{\delta x} \qquad 2.1$$

$$h\ (v) + \overline{v}'w = -\frac{1}{\overline{\rho}}\frac{\delta p}{\delta y} \qquad 2.2$$

$$h\ (w) + \frac{g}{\overline{T}}\,T = -\frac{1}{\overline{\rho}}\frac{\delta p}{\delta z} \qquad 2.3$$

$$\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + w' = 0 \qquad 2.4$$

$$h\ (T) + (\gamma_a + \overline{T}')w = 0 \qquad 2.5$$

Starting with these basic equations, this is the procedure to be followed in order to obtain the vertical wind equation. The operators $\frac{\delta^2}{\delta x\ \delta z}$ and $\frac{\delta^2}{\delta y\ \delta z}$ are applied to 2.1 and 2.2 respectively; hence, after linearization:

$$h\ \left(\frac{\delta u'}{\delta x}\right) + \overline{u}''\frac{\delta w}{\delta x} = -\frac{1}{\overline{\rho}}\frac{\delta^2\ p'}{\delta x^2} - \frac{d\overline{u}}{dz}\frac{\partial^2 u}{\partial x^2} - \frac{d\overline{v}}{dz}\frac{\partial^2 u}{\partial x\partial y}$$

$$h\ \left(\frac{\delta v'}{\delta y}\right) + \overline{v}''\frac{\delta w}{\delta y} = -\frac{1}{\overline{\rho}}\frac{\delta^2 p'}{\delta y} - \frac{d\overline{v}}{dz}\frac{\partial^2 v}{\partial y^2} - \frac{d\overline{u}}{dz}\frac{\partial^2 v}{\partial x\partial y} \qquad (3)$$

and, by addition, by employing 2.4, ∇^2 being the Laplacean operator and ∇_1^2 the horizontal Laplacean operator

$$-\ h\ (w'') + \overline{u}''\frac{\delta w}{\delta x} + \overline{v}''\frac{\delta w}{\delta y} = -\frac{1}{\overline{\rho}}\nabla_1^2\ p' \qquad (4)$$

The substitute operator ∇_1^2 is applied to 2.3 with h

$$\nabla_1^2\ (h(w)) - \frac{g}{\overline{T}}\nabla_1^2\ (T) = -\frac{1}{\overline{\rho}}\nabla_1^2\ (p') \qquad (5)$$

and, by subtracting (5) from (4),

$$-\ \nabla_1^2\ (h(w)) + \frac{g}{\overline{T}}\nabla_1^2\ (T) + \overline{u}''\frac{\delta w}{\delta x} + \overline{v}''\frac{\delta w}{\delta y} = 0 \qquad (6)$$

Finally, by applying the operator h to (6) while elucidating h (T) in accordance with 2.5

$$-h^2\ (\nabla^2(w)) - \frac{g}{\overline{T}}\ (\gamma_a + \overline{T}')\ \nabla_1^2\ (w) + h\ (\overline{u}''\ \frac{\delta w}{\delta x} + \overline{v}''\ \frac{\delta w}{\delta y}) = 0 \qquad (7)$$

This is the vertical wind equation which, in this form, is an equation of the fourth order.

2. SOLUTION OF THE VERTICAL WIND EQUATION IN THE PRESENCE OF CONVECTIVE CELLS

The convective cells can be considered to be a stationary phenomenon, spatially repetitive, comprising at the interior of each cell a sinusoidal vertical wind variation, along the vertical axis and two horizontal axes perpendicular to each other. The vertical wind field hence admits three wavelengths L_x, L_y and L_z, enabling the introduction of the numbers:

$$l = \frac{2\pi}{L_x} \quad ; \qquad m = \frac{2\pi}{L_y} \quad ; \qquad n = \frac{2\pi}{L_z}$$

As an expression of this field, we postulate

$$w = w_M \cos\ (lx)\ \cos\ (my)\ \sin\ (nz) \qquad (8)$$

In the presence of clouds, the maximum ascendancy w_M occurs immediately below the clouds and the maximum descendancy $-w_M$ occurs between the clouds. In the presence of cloudstreets, L_x is the spacing between the centers of two consecutive clouds in a single street, L_y is twice the spacing between the axes of two streets, and L_z is twice the thickness of the convective layer. The following six types of cell were studied:

1. $L_y = Lx = Lz$

2. $L_y = 2Lx = Lz$

3. $L_y = 2Lx = 2Lz$

4. $L_y = 4Lx = 2Lz$

5. $L_y = 2\sqrt{2}\ Lx = 2\sqrt{2}\ Lz$

6. $L_y \simeq 4\sqrt{2}\ Lx \simeq 2\sqrt{2}\ Lz$

These provide for a gradual passage from aerological scale to the mesoscale, by a gradual increase of horizontal dimensions with respect to the vertical dimension.

Types 2, 3 and 4 may correspond to cloudstreets, and types 5 and 6 to open and closed scales of the mesoscale. The structure suggested for the vertical wind field appears to be most reasonable, particularly in the presence of cloudstreets. It is different from that adopted by J.P. Kuettner in his 1971 article.

By introducing structure (8) in the vertical wind equation (7) it will be shown that this may be a solution, provided that one accepts some constraints governing the parameters of this equation. These constraints constitute the interesting part of the model, by conditioning the vertical variation of the horizontal wind. We are thus faced with a reverse method for determining the wind profile.

3. PRINCIPLE OF THE DETERMINATION OF THE WIND PROFILE

Assuming the following auxiliary variables:

$$d^2 = l^2 + m^2 + n^2$$

$$X = \sin(lx),\; X' = \cos(lx)$$

$$Y = \sin(my),\; Y' = \cos(my)$$

$$Z = \sin(nz),\; Z' = \cos(nz)$$

If we replace W, the Laplacean operators, the operator h and the partial derivatives of w by their expressions as a function of X, Y, Z, X', Y', Z', we obtain:

$$d^2h^2(w) + \frac{g}{\overline{T}}(\gamma_a + \overline{T})(l^2 + m^2)w + h\left(\overline{u}'' \frac{\delta w}{\delta x} + \overline{v}'' \frac{\delta w}{\delta y}\right) = 0 \qquad (9)$$

with

$$d^2h^2(w) = d^2W_M \left[\left(-l^2\overline{u}^2 - m^2\overline{v}^2\right)X'Y'Z + 2lm\,\overline{u}\,\overline{v}\,X\,Y\,Z\right]$$

$$\frac{g}{\overline{T}}(\gamma_a + \overline{T}')(l^2 + m^2)w = \frac{g}{\overline{T}} W_M (\gamma_a + \overline{T}')(l^2 + m^2)\,X'Y'Z$$

$$h\left(\overline{u}'' \frac{w}{x} + \overline{v}'' \frac{w}{y}\right) = W_M \left[\left(-l^2\overline{u}\,\overline{u}'' - m^2\overline{v}\,\overline{v}''\right)X'Y'Z + lm\left(\overline{v}\,\overline{u}'' + \overline{u}\,\overline{v}''\right)XYZ\right] \qquad (10)$$

The vertical wind equation can then be written

$$lm\left(2d^2\overline{u}\,\overline{v} + \overline{u}\,\overline{v}'' + \overline{v}\,\overline{u}''\right)XY + \left[\frac{g}{\overline{T}}(\gamma_a + \overline{T}')(l^2+m^2) - l^2\overline{u}\,\overline{u}'' - m^2\overline{v}\,\overline{v} - d^2\left(l^2\overline{u}^2 + m^2\overline{v}^2\right)\right]X'Y' = 0$$

Since this equation must be satisfied at all points x,y, it must also be satisfied for each of the two pairs XY and X'Y'. We must thus have a vertical wind structure such that at any level z, the two horizontal wind components $\overline{u}$ and $\overline{v}$ satisfy the system:

$$2\,d^2\,\bar{u}\,\bar{v} + \bar{u}\,\bar{v}'' + \bar{v}\,\bar{u}'' = 0$$

$$\frac{g}{\bar{T}}\,(\gamma_a + \bar{T}')(l^2 + m^2) - l^2\,\bar{u}\,\bar{u}'' - m^2\,\bar{v}\,\bar{v}'' - d^2(l^2\bar{u}^2 + m^2\bar{v}^2) = 0 \qquad (11)$$

In other words, by writing the vertical thermal gradient with its usual notation γ, and taking T_o as the air temperature at the ground:

$$\bar{u}'' = \left[\frac{g\,(l^2 + m^2)\,(\gamma - \gamma_a)}{(T_o - \gamma z)(-\,l^2u^2 + m^2v^2)} - d^2\right]\,\bar{u}$$

$$\bar{v}'' = \left[\frac{g(l^2 + m^2)(\gamma - \gamma_a)}{(T_o - \ z)(l^2u^2 - m^2v^2)} - d^2\right]\,\bar{v} \qquad (12)$$

Note that for an adiabatic gradient, we have

$$\frac{\bar{u}''}{\bar{v}''} = \frac{\bar{u}}{\bar{v}}$$

In other words, a sinusoidal wind variation ~~with a maximum at the middle of the convective layer~~. with a maximum a little below the middle of the convective layer.

Within a convective cell, system (12) can be accepted as a necessary constraint governing the wind profile. It can be noted that in the case of streets which are indefinitely oriented in the wind direction, namely, in the case of two-dimensional rolls, system (11) is reduced to

$$\frac{g}{\bar{T}}\,(\gamma_a + \bar{T}')m^2 = 0 \qquad (15)$$

leading to the need for an adiabatic thermal gradient.

4. NUMERICAL CALCULATION OF THE WIND PROFILE

To process numerically equation (12), we approximate the secondary derivatives $\overline{u}''$ and $\overline{v}''$ by finite differences of the type:

$$\overline{u}''_i \simeq \frac{\overline{u}_{i+1} - 2\overline{u}_i + \overline{u}_{i-1}}{\Delta z^2}$$

$$\overline{v}''_i \simeq \frac{\overline{v}_{i+1} - 2\overline{v}_i + \overline{v}_{i-1}}{\Delta z^2}$$

where $\overline{u}$ and $\overline{v}$ are the wind components at level $i\Delta z$. As a value of Δz, it is sufficient to take a number of the order of $L_z'/1000$. In practice, one generally takes $\Delta z = 10$ m.

By writing:

$$A_i = \frac{g(l^2 + m^2)(\gamma - \gamma_a)}{T_0 - i\gamma\Delta z}$$

we obtain the recurrence formulas

$$u_i = \frac{A_{i-1}\,\Delta z^2\, u_{i-1}}{-l^2 u_{i-1}^2 + m^2 v_{i-1}^2} + (2 - d^2\Delta z^2)\,u_{i-1} - u_{i-2}$$

$$v_i = \frac{A_{i-1}\,\Delta z^2\, v_{i-1}}{l^2 u_{i-1}^2 - m^2 v_{i-1}^2} + (2 - d^2\Delta z^2)\,v_{i-1} - v_{i-2} \qquad (16)$$

The two horizontal wind components u_i and v_i at level $i\Delta z$, along the two perpendicular direction L_x and L_y, may thus be calculated by iteration, as a function of u_{i-1}, u_{i-1}, v_{i-1}, v_{i-1}.

The wind can thus be calculated at all levels, if it is known at the two first levels, level 1, the ground level, and level 2, the Δz level.

However, it is easier to know the wind at level $L_Z/2$, the top of the convective layer, than at level 2. The wind at level 2 may be obtained by a rapidly convergent calculation of successive approximations, based on a linear error interpolation, of which the algorithm is given below.

The procedure suggested for obtaining the wind profile, based on equations (16), is only consistent if the denominator $- l^2 u_i^2 + m^2 v_i^2$ always maintains its original sign, which must be checked at each step. The wind is only calculated inside the convective layer $L_Z/2$; it is printed at 100 meter intervals.

5. ALGORITHM FOR CALCULATING THE WIND AT LEVEL Δz

Let the values of the wind components at the ground be UR_1, VR_1, and at the top UR_H and VR_H. For level 2, corresponding to level Δz, we first assume two arbitrary values, for example:

$$UG_1 = UR_1 + \Delta_z \times 10^{-3}$$

$$VG_1 = VR_1 + \Delta z \times 10^{-4}$$

The iterative calculation from UR_1, UG_1, VR_1 and VG_1 leads to level H corresponding to $L_Z/2$, at values UC_1 and VC_1. We thus

know the errors

$P_1 = UR_1 - UC_1$

$Q_1 = VR_1 - VC_1$

These cannot be acceptable unless

$$P_1^2 + Q_1^2 < 0.01 \qquad (17)$$

If not, we can calculate the successive terms of a guess field of the values of the wind components at level 2, UG_N and VG_N, to finally arrive, by employing the iteration equations (16), at the wind component values at level H satisfying equation (17).

In order to do this, we take the preceding terms as the successive values of the guess field, corrected by linearly extrapolating the simultaneous influence of a very slight variation in UG and VG on the two components of the error at the top P_N and Q_N.

$P_N = UR_H - UC_N$

$Q_N = VR_H - VC_N$

For example, VG_N and $(UG_N + 0.0001)$ produce differences dp_1 in P_N and dq_1 in Q_N, and $(VG_N + 0.0001)$ and UG_N produce differences dp_2 in P_N and dq_2 in Q_N.

We have the equations:

$x\, dp_1 + y\, dp_2 = P_N$

$x\, dq_1 + y\, dq_2 = Q_N$

From this we deduce:

$$x = \frac{dq_2\, P_N - dp_2\, Q_N}{dp_1\, dq_2 - dp_2\, dq_1}, \quad y = \frac{dp_1\, Q_N - dq_1\, P_N}{dp_1\, dq_2 - dp_2\, dq_1}$$

and the iteration formulas

UG(N) = UG(N-1) + 0.001 x

VG(N) = VG(N-1) + 0.001 y (18)

We leave the algorithm for one of the two following conditions, stated arbitrarily:

$P(N)^2 + Q(N)^2 < 0.01$

N = 10

In fact, this system is very rapidly convergent and one generally obtains the wind at level Δz for N = 2 or 3.

6. DETERMINATION OF THE TYPE OF CELL AND OF THE CORRESPONDING WIND PROFILE

Up to this point, we have ignored the friction forces. They will now be accounted for by assuming that the type of cell which should be retained from among the six types considered will be that corresponding to a minimization of these forces.

If we assume that the friction forces have the form $\nu \frac{\partial^2 \vec{V}}{\delta z^2}$ with a turbulent kinematic viscosity coefficient ν which is constant, the friction force per unit weight is proportional at any level to $\vec{V}''$.

For each type of cell, the following sum is calculated

$$\sum \vec{V}_i \cdot \vec{V}''_i \tag{19}$$

$i = 10,20,30,\ldots,L_z/2-10$

This represents, at the thickness of the convective layer, a quantity proportional to the energy dissipated per unit time by the friction forces. It should be noted that, owing to the fact that each term is a scalar product of two vectors of which the components are known, its calculation is especially easy to program. Finally, the type of cell retained is that corresponding to the minimum value of this sum.

We thus obtain the wind profile at the interior of the convective layer, for a given characteristic dimension, whether this is the thickness of the convective layer, derived from a radiosounding, or the inter-street spacing, measured from a satellite picture, and from the information concerning the movement and temperature of the air at the ground level and at the top of the convective layer.

The following page shows the table giving the type of cell to be retained, and consequently enabling the calculation of the corresponding wind profile, as a function of γ and L_y, γ varying from 50.10^{-4} to 100.10^{-4} deg.m^{-1} and L_y varying from 2 to 100 km, for

0 - No solution
1 - $L_Z = L_Y \quad L_X = L_Y$
2 - $L_Z = L_Y \quad L_X = L_Y/2$
3 - $L_Z = L_Y/2 \quad L_X = L_Y/2$
4 - $L_Z = L_Y/2 \quad L_X = L_Y/4$
5 - $L_Z = L_Y/2\sqrt{2} \quad L_X = L_Y/2\sqrt{2}$
6 - $L_Z = L_Y/2\sqrt{2} \quad L_X = L_Y/4\sqrt{2}$

TYPES OF CELL AS A FUNCTION OF L_Y AND γ

L_Y	50	55	60	65	70	75	80	85	90	95	100.10^{-4} deg.m^{-1}
100000 m	0	0	0	0	0	0	0	0	6	6	0
90000	0	0	0	0	0	0	0	0	0	6	0
80000	0	0	0	0	0	0	6	6	5	6	0
70000	0	0	0	0	0	6	6	5	5	5	0
60000	0	0	0	6	6	5	5	5	6	5	0
50000	6	6	4	5	5	5	5	6	6	3	0
40000	5	5	5	5	5	6	6	6	4	3	0
30000	5	6	6	6	6	5	4	4	3	2	0
28000	6	6	6	6	6	5	4	5	3	2	0
26000	6	6	6	6	5	4	4	3	3	2	0
24000	6	6	6	5	4	4	5	3	3	2	0
22000	6	5	5	4	4	5	3	3	2	1	0
20000	5	4	4	4	5	3	3	3	2	1	0
18000	4	4	4	5	3	3	3	3	2	1	0
16000	4	5	5	3	3	3	3	2	2	1	0
14000	3	3	3	3	3	3	2	2	1	1	0
12000	3	3	3	3	2	2	2	2	1	1	0
10000	3	2	2	2	2	2	2	1	1	0	0
9000	2	2	2	2	2	2	1	1	1	0	0
8000	2	2	2	2	2	1	1	1	1	0	0
7000	2	2	2	1	1	1	1	1	1	0	0
6000	1	1	1	1	1	1	1	1	0	0	0
5000	1	1	1	1	1	1	1	1	0	0	0
4000	1	1	1	1	1	1	0	0	0	0	0
3000	1	1	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0

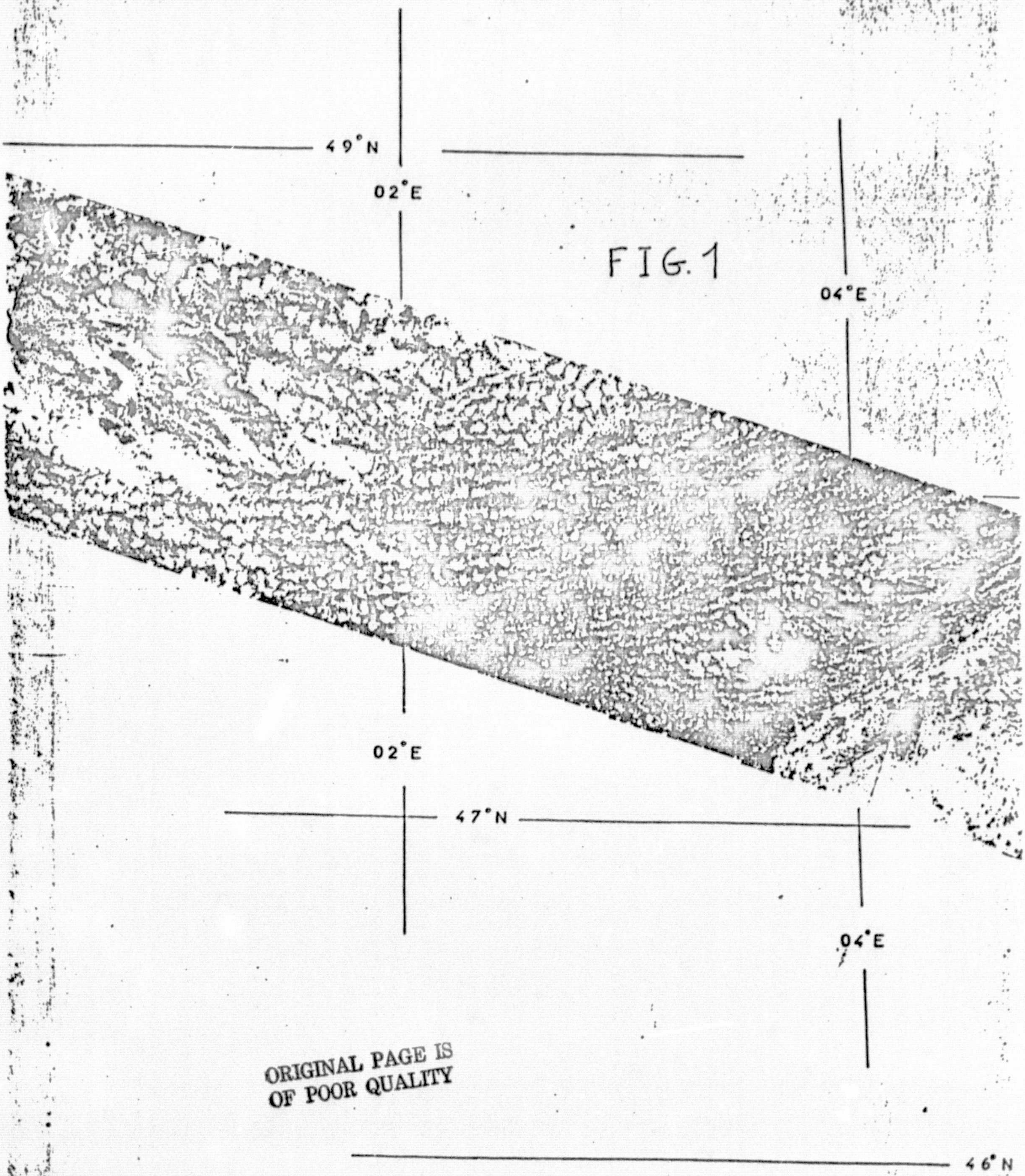
a ground wind at 270° and 8 ms^{-1}, a wind at the top of the convective layer at 280° and 9 ms^{-1}, a street direction of 280, corresponding to an x axis of 250°-100°, a ground temperature of 288°K.

It has been noted that the ground temperature has very little influence, and that a variation of about 20° only slightly modifies the corresponding wind profile. In the table can also be noted the regions of (L_y,γ) in which the calculation is impossible, owing to a sign change in the denominator during the iteration.

The appendix contains a general calculation flowchart and the corresponding programs in Fortran language. The programs were developed by S. Senotier.

7. RESULTS OBTAINED WITH SKYLAB

The Bureau d'Etudes de Météorologie Spatiale of the Météorologie Nationale Française undertook an in-flight experiment on Skylab III, which enabled accurate measurements to be taken on a case of cloudstreets observed on 19 September 1973 over France. The data obtained through these measurements led to this study.


49°N
02°E
FIG. 1
04°E
02°E
47°N
04°E
46°N

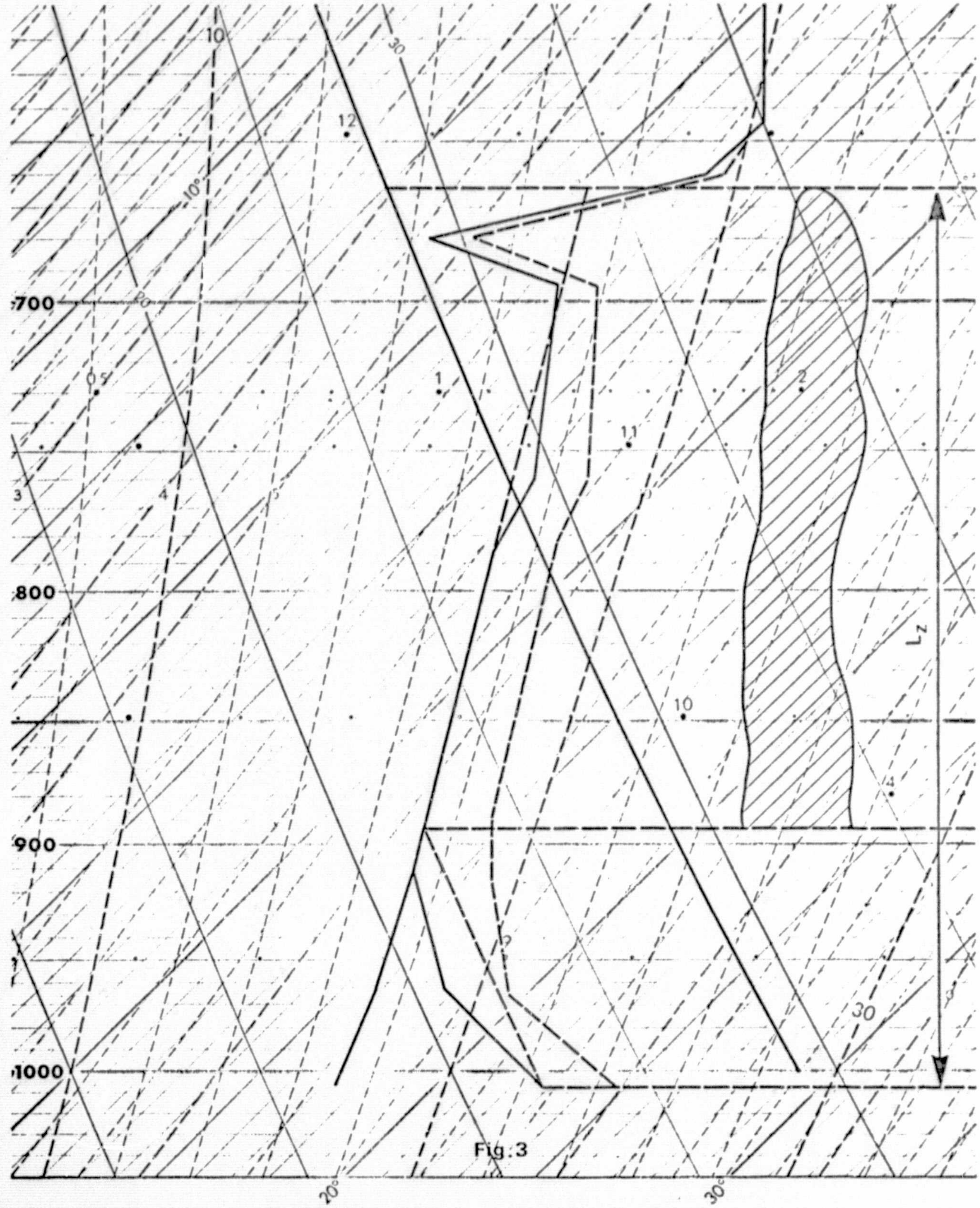


Fig. 3

BORDEAUX

le 9/19/1973 à 12.00 h. T.U.

On 19 September 1973, at 1400 T.V., the astronauts of Skylab III took cumulus alignment pictures over the center of France, over a zone covering about 10^{4} square kilometers. The topography and general direction of the winds revealed that this is not a case of relief waves but truly a case of cloudstreets. The mean direction (255°) was taken as the alignment direction, and the spacings L_X and L_Y were measured from the pictures of S190 B. The Bordeaux 1200 T.V. radiosounding supplied the values of the other parameters required by the model (V_o = 8.2 ms^{-1} and 240°, V_h = 8.7 and 252°, T_o = 295.8, γ = 0.0059).

Figures 1 and 2 represent the pictures of these streets at small and large scales. The large-scale pictures were derived from S190 B, and the small-scale pictures are mosaic montages of documents derived from the instrument S190 A.

In the Bordeaux 1200 T.V. radiosounding of 19 September 1973, one can note a convective layer thickness of 3500 m (figure 3), corresponding to a L_Z of 7000 m. L_Z is taken as the characteristic dimension and the comparison of the six types of cell indicates that type No. 3, corresponding to the structure L_Z = 7000, L_Y = 14,000, L_X = 7000 m, satisfies the criterion of the minimization of internal energy dissipation. This type 3 structure also corresponds to the spacings measured from S190 B pictures, if one adheres to the measurements taken from the largest clouds. It can be noted that the inter-street spacing thus corresponds to twice the thickness of the convective layer.

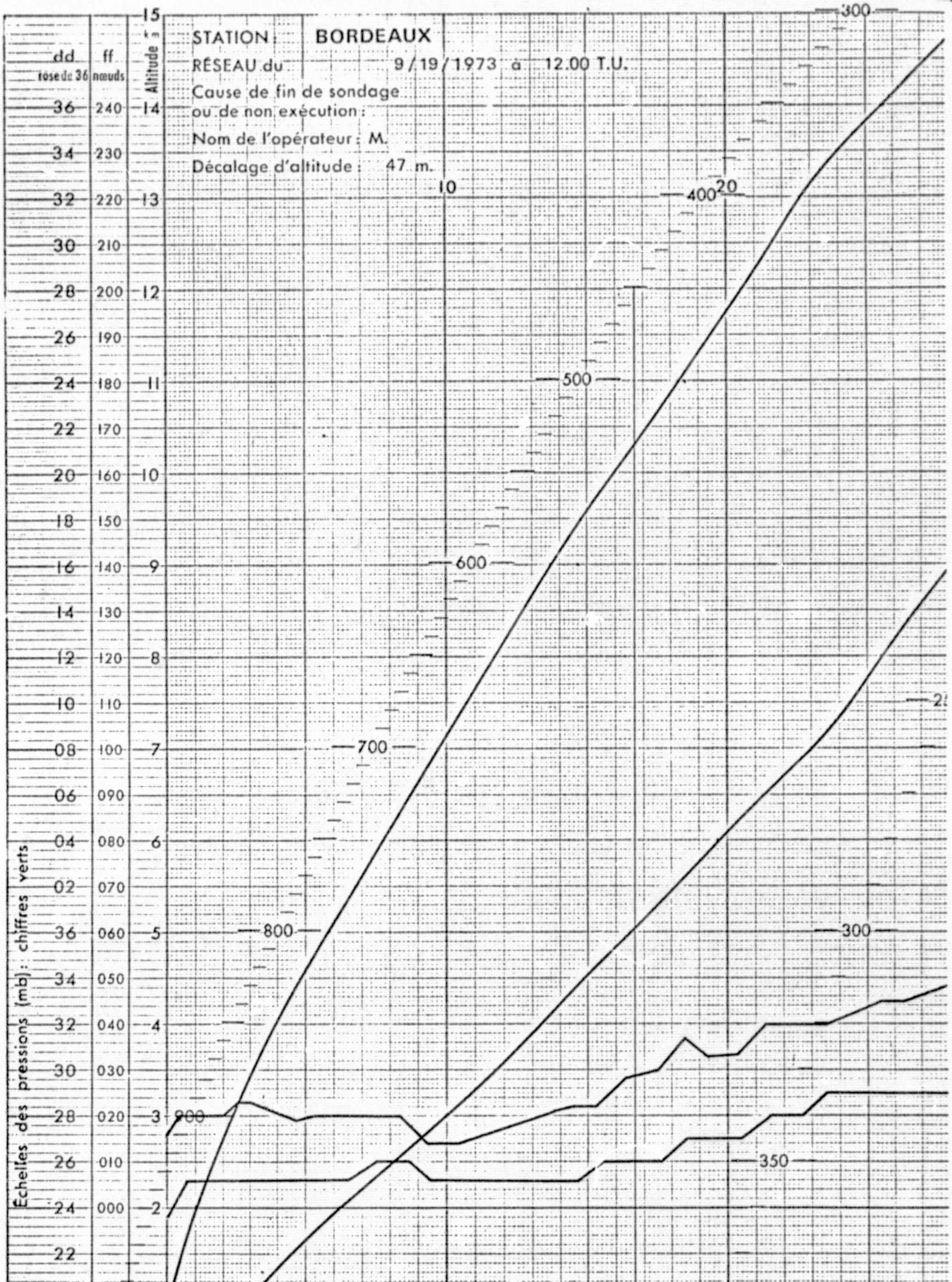


Fig. 4

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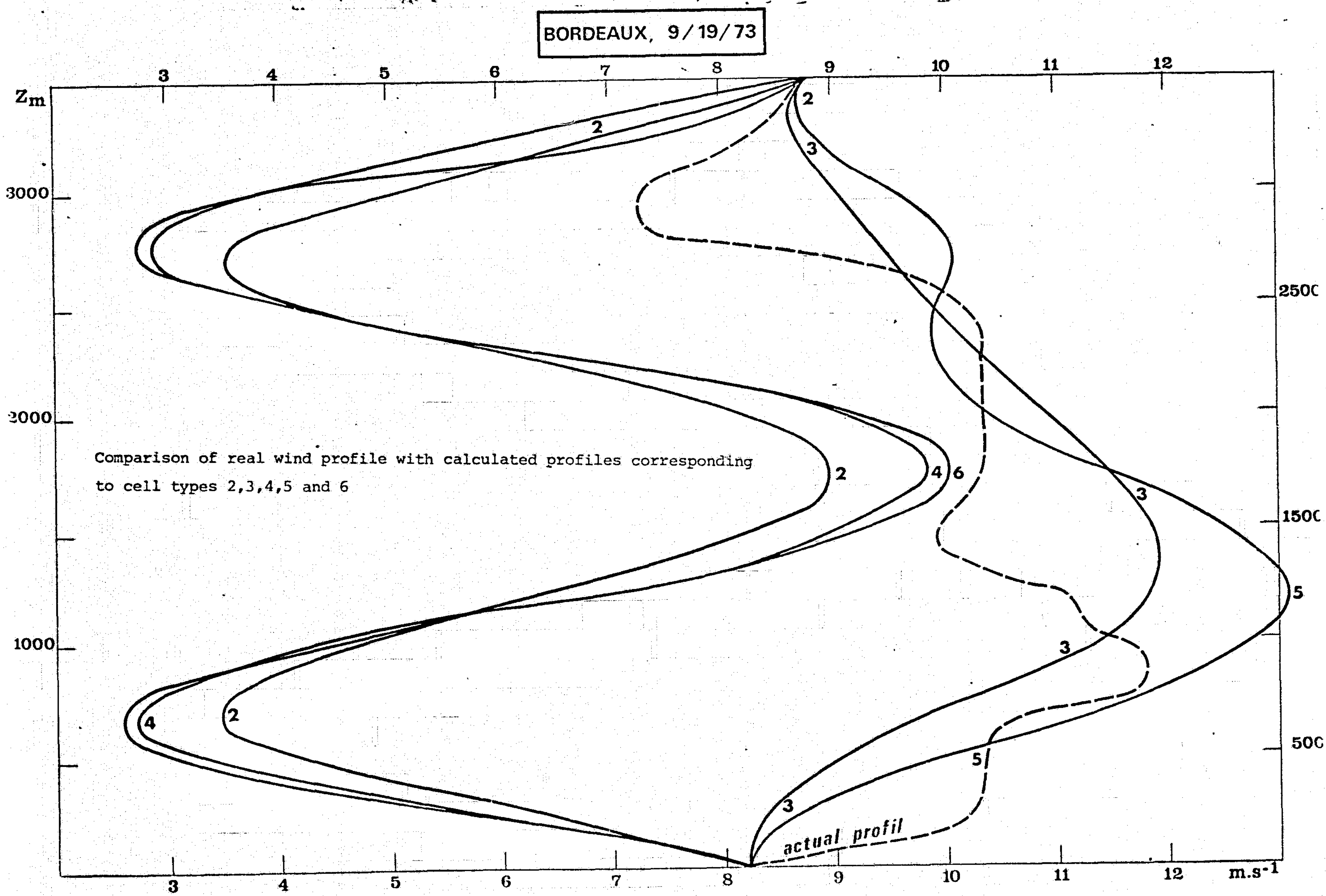

BORDEAUX, 9/19/73
Zm
3000
2000
1000
2500
1500
500
3
4
5
6
7
8
9
10
11
12
m.s-1
Comparison of real wind profile with calculated profiles corresponding to cell types 2,3,4,5 and 6
actual profil

Fig. 5

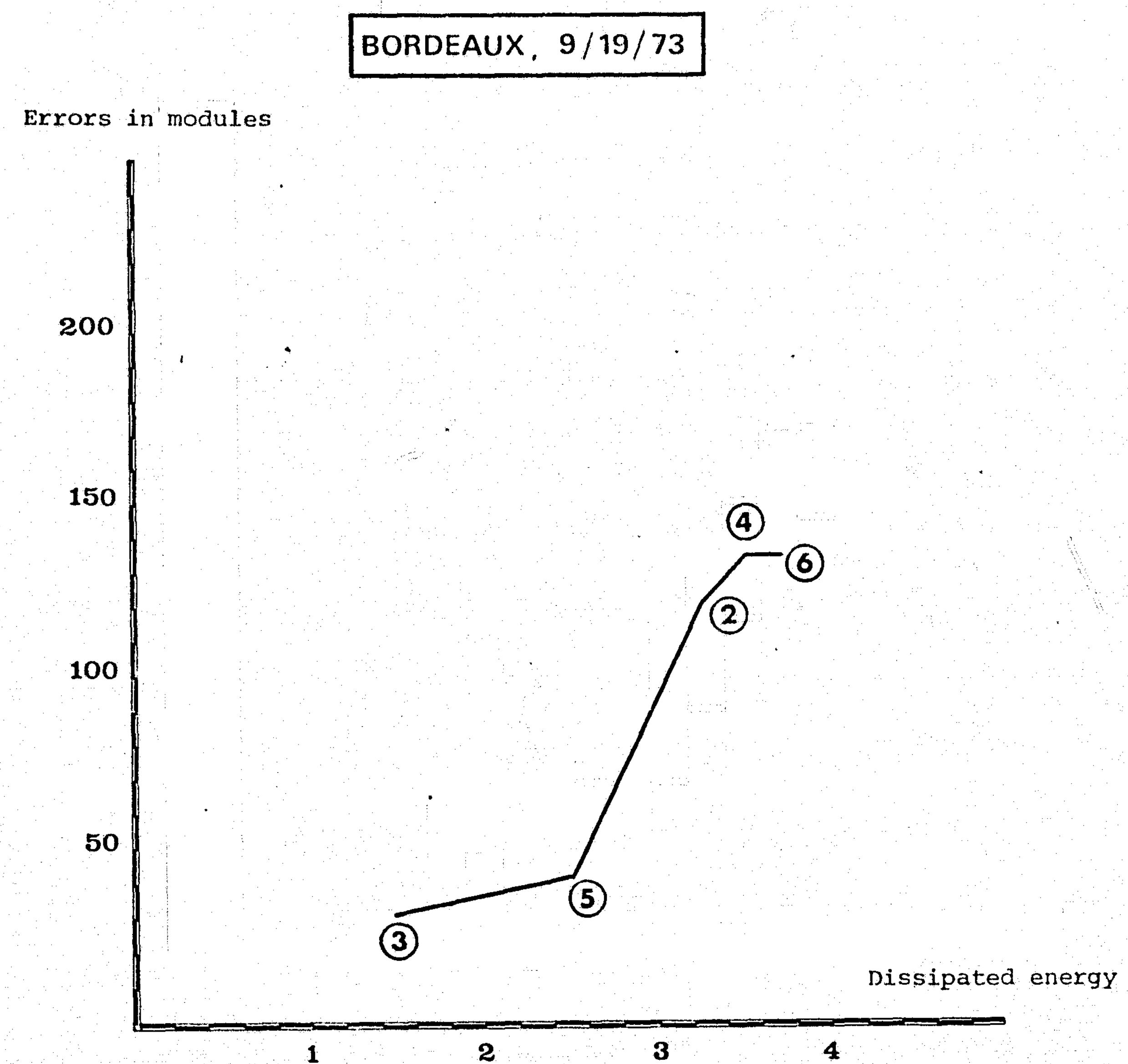


Fig. 6

Comparison of the errors with internal energy dissipation, for the different types of cell

Type 1, corresponding to a symmetric cell, leads to a numeric impossibility. Figure 5, which compares the five calculated profiles to the real profile from the Bordeaux radiosounding, again shows that the type 3 structure provides the best profile. Figure 6 shows the comparison, for each profile, of the total deviation from the real profile with the total energy dissipated. The error in the calculated profile with respect to the real profile is approximately proportional to the energy dissipated, confirming the value of the criterion employed. We have thus retained the type 3 structure.

It can finally be stated that, for 19 September 1973, a comparison of the wind profiles supplied by the model and by the Bordeaux sounding reveal a relatively slight difference (fig. 7). It can also be observed that in both cases, the maximum wind is very close to 12 ms^{-1}. Moreover, the influence of viscosity can account for the reduction in the wind rotation, when going from the model to the real wind.

8. PROSPECTS

In conclusion, the result obtained in this particular case, thanks to Skylab, has enabled the construction of a model which provides the wind profile by a sort of inverse calculation, starting from the conditions prevailing at the limits and from a simple morphological parameter which is easily measurable.

BORDEAUX, 9/19/73

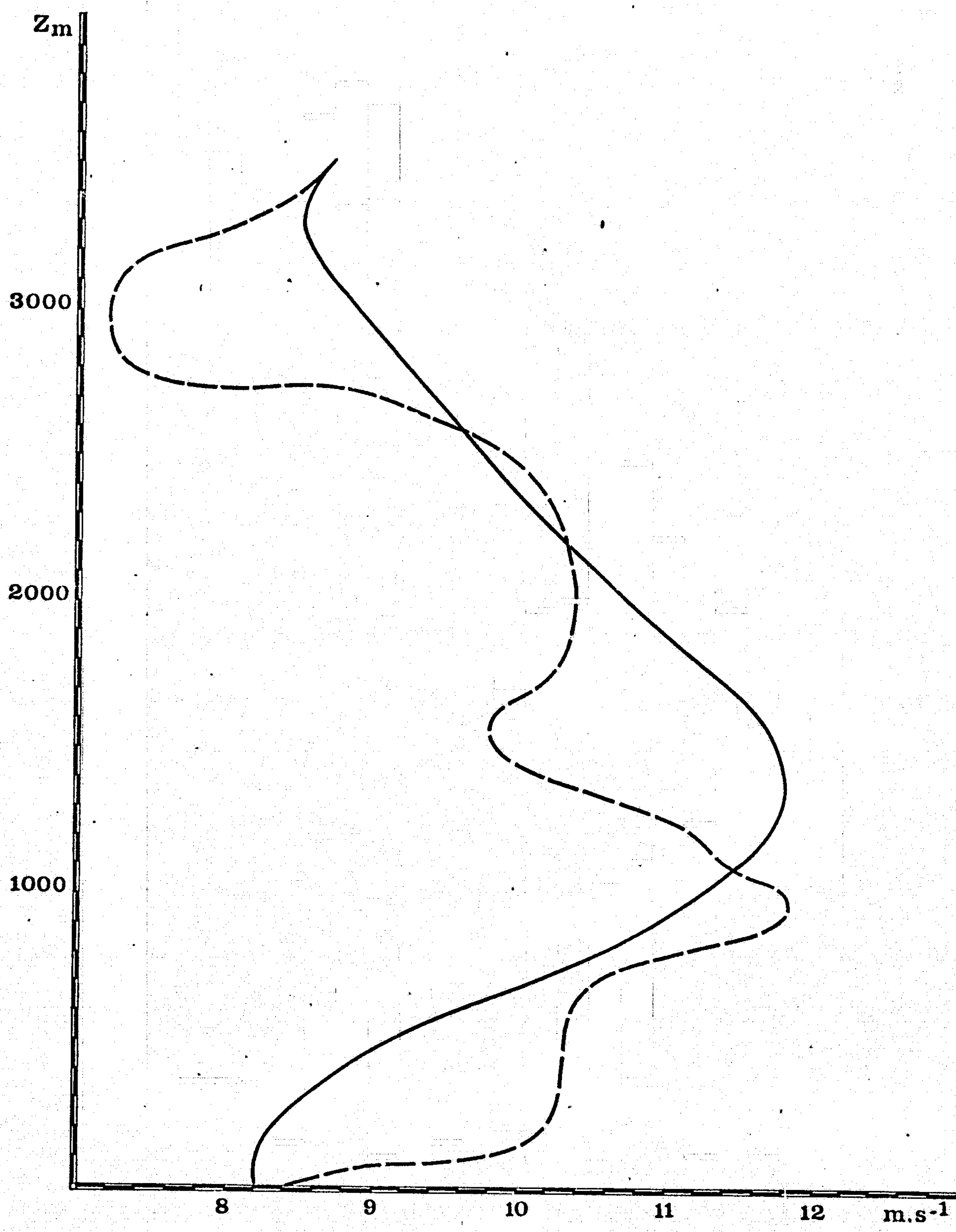


Fig. 7

It would be interesting to test this model on a sufficient number of radiosoundings by selecting adequate radiosoundings, namely, those corresponding to vertical hypothermal structures for which it would be possible to determine the thickness of the convective layer, and for which wind profile measurements are available at the same locations and at the same times.

Should the results of such a comparison prove satisfactory, one could then try to apply this method to satellite pictures of cloudstreets, taking the inter-street spacing as the characteristic dimension. The mean thermal gradient can then be derived from the surface temperature supplied by VHRR, and the direction of the streets themselves could be taken as the wind directions at the ground and at the top of the convective layer.

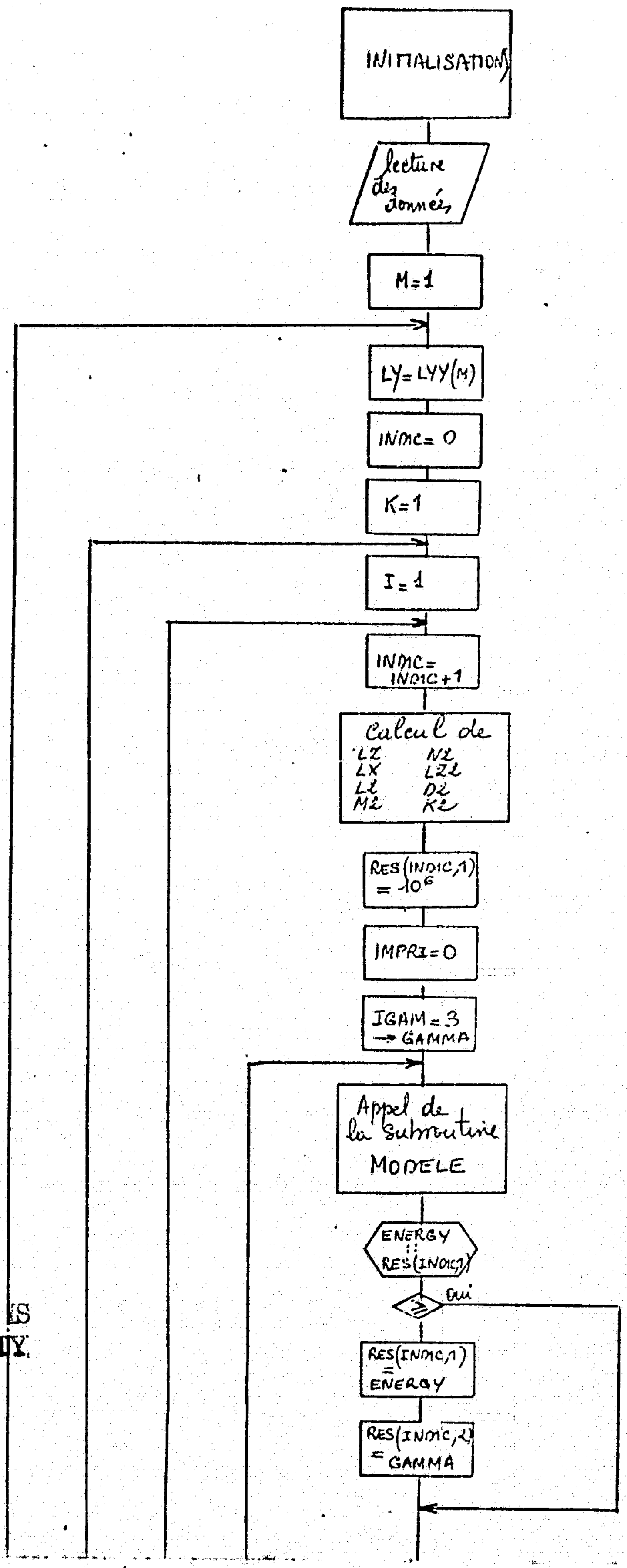
These verifications only will confirm whether the proposed model offers a possibility for operational use.

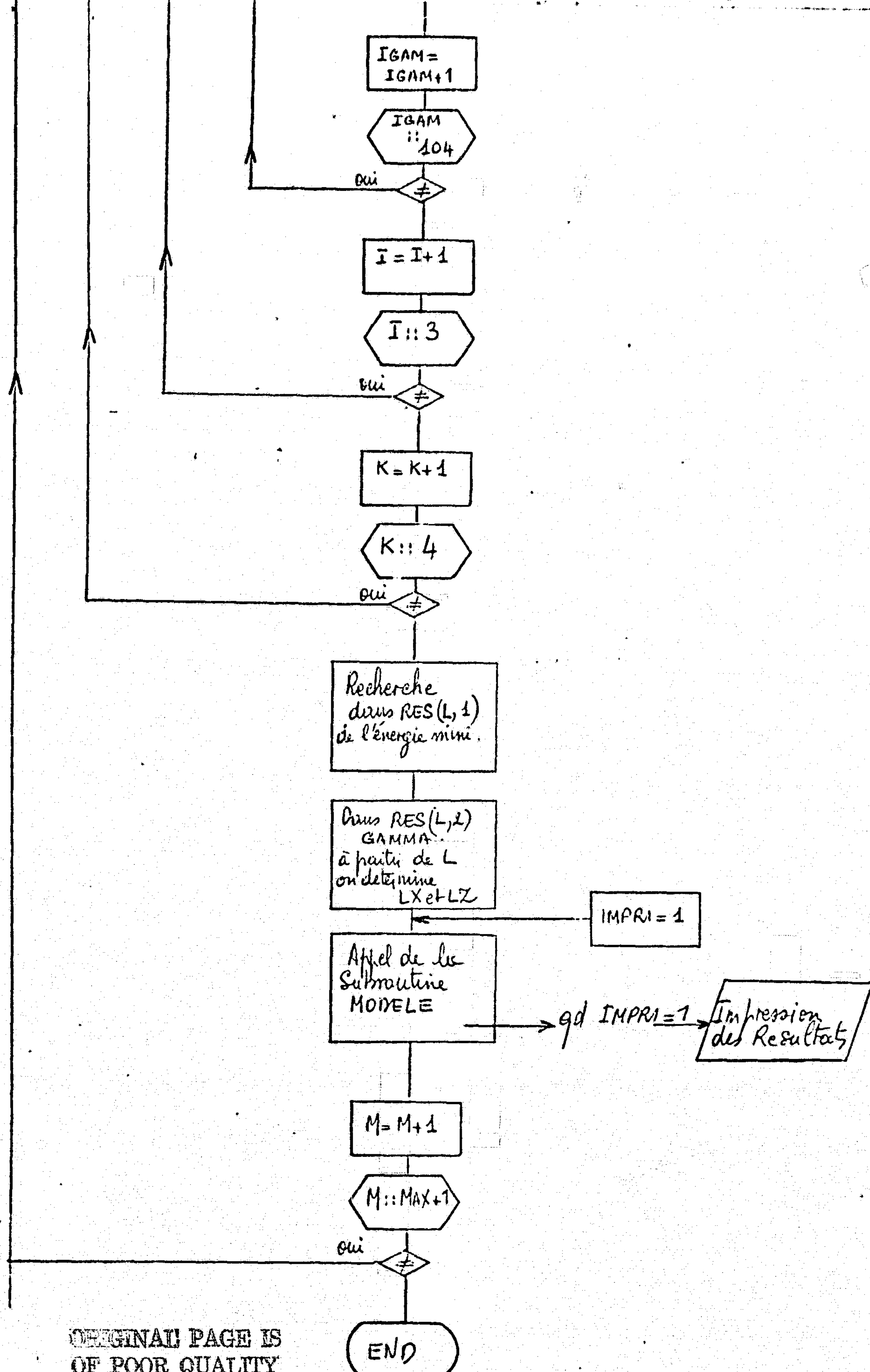
1. J.P. Kuettner, Cloud Bands in the Earth's Atmosphere, Tellus XXIII, 1971.

Tables, figures and documents attached:

Tables showing types of cell as a function of L_y and γ

Fig. 1	Mosaic of pictures taken by S190 A of Skylab III
Fig. 2	Cloudstreets seen by S190 B
Fig. 3	Bordeaux radiosounding on 19 September 1973
Fig. 4	Bordeaux radiowind on 19 September 1973
Fig. 5	Comparison of calculated profiles and real profile
Fig. 6	Diagram of "error as a function of energy dissipated"
Fig. 7	Comparison of type 3 profile with real profile
Fig. 8	General flowchart
Fig. 9	Fortran program for determination of the type of cell
Fig. 10	Fortran program for wind profile


INITIALISATION
lecture des données
M=1
LY=LYY(M)
INDIC= 0
K=1
I=1
INDIC= INDIC+1
Calcul de
LZ NZ
LX LZZ
LZ DZ
MZ KZ
RES(INDIC,1) = -10^6
IMPRI=0
IGAM=3 → GAMMA
Appel de la subroutine MODELE
ENERGY :: RES(INDIC,1)
≥
oui
RES(INDIC,1) = ENERGY
RES(INDIC,2) = GAMMA


IGAM = IGAM+1
IGAM :: 104
oui
≠
I = I+1
I :: 3
oui
≠
K = K+1
K :: 4
oui
≠
Recherche dans RES(L, 1) de l'énergie mini.
Dans RES(L,2) GAMMA à partir de L on détermine LX et LZ
IMPRI = 1
Appel de la Subroutine MODELE
qd IMPRI = 1
Impression des Resultats
M = M+1
M :: MAX+1
oui
≠
END

```
      PROGRAM RUEGENE(INPUT,OUTPUT)
      DIMENSION TAB(10,11),IGG(11)
      DIMENSION CAS(3),LYY(10),RES(6,2)
      DIMENSION DDR(3)
      DATA(DDR(I),I=1,3)/240.,252.,270./
      DATA(CAS(I),I=1,2)/1.,2./
      REAL LYY
      REAL LX,LY,LZ,M2,N2,L2,LZ2
      COMMON/LIEU/IDATE(4),PAS,IPAS
      COMMON/RESULT/UG(4000),VG(4000),ZZ(4000)
      COMMON/PARAM/TO        ,L2,M2,N2,GAMMAA ,Q,G,GAMMA,PI,LX,LY,LZ
      COMMON/SOND/IALT(351),VPI(351),DRI(351)
      DATA PI,G,GAMMAA /3.141593,9.81,.0097671/
      CAS(3)=2*SQRT(2.)
      PAS=10
      Q=PAS*PAS
      IPAS=50
      READ 1     ,(IDATE(I),I=1,4)
    1 FORMAT(4A10)
      READ 2      ,VENZ1,DIRZ1,TO
      FORMAT(3F10.1)
      READ 2      ,VENZZ,DIRZZ
      READ 3, DR
      FORMAT(     F10)
      MM=0
      DO 700 M=1,10
      MM=MM+1
      LY=1600+(M-1)*100
      IG=0
      DO 300 IGAM=50,100,5
      GAMMA=IGAM*1.E-04
      IG=IG+1
      INDIC=0
      DO 400 K=1,3
      DO 400 I=1,2
      INDIC=INDIC+1
      LZ=LY/CAS(K)
      LX=LZ/I
      L2=(2*PI/LX)**2
      M2=(2*PI/LY)**2
      N2=(2*PI/LZ )**2
      LZ2= LZ/2
      D2=M2+N2+L2
      K2 = LZ2/PAS+1
      RES(INDIC,1)=1.E06
      IMPRI=0
      CALL MODELE(DR,DIRZ1,VENZ1,DIRZZ,VENZZ,K2,ENERGY,IMPRI)
      IF(ENERGY.GT.RES(INDIC,1)) GO TO 300
      RES(INDIC,1)=ENERGY
      RES(INDIC,2)=GAMMA
   )0 CONTINUE
      I=1
      J=2
   )1 IF((RES(J,1)).GE.(RES(I,1))) GO TO 402
      I=J
   )2 J=J+1
      IF(J.LT.7) GO TO 401
```

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```
      J=0
      DO 500 K=1,3
      DO 500 IND=1,2
      J=J+1
      IF(J.EQ.I) GO TO 501
500 CONTINUE
501 LZ=LY/CAS(K)
      GO TO 502
502 IF(RES(I,1).EQ.1.E06) I=0
      TAB(MM,IG)=I
800 CONTINUE
700 CONTINUE
      DO 600 I=1,11
600 IGG(I)=(I-1)*5+50
      PRINT 701
701 FORMAT(1H1,40X,* 0 = PAS DE SOLUTION*,/,
   S1H ,40X,* 1 - LZ=LY            LX=LZ*,/,
   S1H ,40X,* 2 - LZ=LY             LX=LZ/2*,/,
   S1H ,40X,* 3 - LZ=LY/2          LX=LZ*,/,
   S1H ,40X,* 4 - LZ=LY/2          LX=LZ/2*,/,
   S1H ,40X,28H 5 - LZ=LY/(2*SQRT(2)) LX=LZ, /,
   S1H ,40X,31H 6 - LZ=LY/(2*SQRT(2)) LX=LZ/2 )
      PRINT 801 ,(IGG(I),I=1,11)
801 FORMAT(1H0,6X,1H*,11I10,/,1H ,117(1H*))
      DO 800 MM=1,10
      M=1000+100*(MM-1)
800 PRINT 900, M,(TAB(MM,I),I=1,11)
900 FORMAT(1H ,I6,1H*,11F10)
      STOP
      END
```

```
      SUBROUTINE MODELE(DF,DIRZ1,VENZ1,DIRZZ,VENZZ,K2,ENERGY,IMPRI)
      DIMENSION UG(10),VG(10),UC1(10),VC1(10),UC2(10),VC2(10),P(10),R(10
     S),U1(10),V1(10)
      COMMON/PARAM/T0          ,L2,M2,D2,GAMMAA  ,O,G,GAMMA,PI,LX,LY,LZ
      COMMON/RESULT/UC(4000),VC(4000),ZZ(4000)
      REAL LX,LY,LZ,M2,N2,L2,LZ2
      COMMON/LIEU/IDATE(4),PAS,IPAS
      COMMON/SOND/IALT(351),VRI(351),DRI(351)
      DO 100 J=1,K2
      ZZ(J)=PAS*(J-1)
00    CONTINUE
      CALL UV(DR,DIRZ1,VENZ1,URZ1,VRZ1)
      CALL UV(DR,DIRZZ,VENZZ,URZZ,VRZZ)
      CALCUL DE LA PREMIERE VALEUR DU GUESS FIELD
      UG(1)=URZ1+PAS*1E-3
      VG(1)=VRZ1+PAS*1E-4
      CALL CALCUL(URZ1,UG(1),VRZ1,VG(1),K2,PAS,U1(1),V1(1),NU)
      IF(NU.EQ.1) GO TO 201
      P(1)=URZZ-U1(1)
      R(1)=VRZZ-V1(1)
      CALCUL DES AUTRES VALEURS DU GUESS FIELD - UG(N),VG(N)
      DO 200 N=1,10
      UG1=UG(N)+.0001
      VG1=VG(N)
      CALL CALCUL(URZ1,UG1,VRZ1,VG1,K2,PAS,UC1(N),VC1(N),NU)
      DP1=UC1(N)-U1(N)
      DR1=VC1(N)-V1(N)
      UG2=UG(N)
      VG2=VG(N)+.0001
      IF(NU.EQ.1) GO TO 201
      CALL CALCUL(URZ1,UG2,VRZ1,VG2,K2,PAS,UC2(N),VC2(N),NU)
      IF(NU.EQ.1) GO TO 201
      DP2=UC2(N)-U1(N)
      DR2=VC2(N)-V1(N)
       UG(N+1)=UG(N)+1.E-4*(DR2*P(N)-DP2*R(N))/(DP1*DR2-DP2*DR1)
      VG(N+1)=VG(N)+1.E-4*(DP1*R(N)-DR1*P(N))/(DP1*DR2-DP2*DR1)
      CALL CALCUL(URZ1,UG(N+1),VRZ1,VG(N+1),K2,PAS,U1(N+1),V1(N+1),NU)
      IF(NU.EQ.1) GO TO 201
       P(N+1)=URZZ-U1(N+1)
      R(N+1)=VRZZ-V1(N+1)
      W1=P(N+1)**2+R(N+1)**2
      IF(W1.LT.0.01) GO TO 50
00    CONTINUE
      NU=1
01    ENERGY=1.E06
      GO TO 400
50    CONTINUE
      ENERGY=0
      L=K2-1
      DO 300 J=2,L
      DUC=    UC(J+1)-2*UC(J)+UC(J-1)
      DVC=    VC(J+1)-2*VC(J)+VC(J-1)
      ENERGY=ENERGY+ABS(UC(J)*DUC+VC(J)*DVC)
00    CONTINUE
00    CONTINUE
      IF(IMPRI.EQ.0) GO TO 500
      PRINT 8
```

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```
 6 FORMAT(1H1,40X,*NUMERICAL APPLICATIONS OF LINEAR THEORY OF CLOUDS
  STREETS*,/,1H0,61X,*(WIND PROFILE)*///)
   PRINT 510,(IDATE(I),I=1,4)
10 FORMAT(1H0,59X,4A10,//,1H0,64X,*DATA*)
   PRINT 520,DR,LX,LY,LZ,VENZ1,DIRZ1,VENZZ,DIRZZ,TC,GAMMA
20 FORMAT(1H0,49X*DR*8X*LX*8X*LY*8X*LZ*/49X,F3,3F10//40X*VVO*7X*DDO*
  S7X*VVH*7X*DDH*8X*TO*5X*GAMMA*/39X,F4.1,F10,F10.1,F10,F10.1,F10.4)
   IF(NU.EQ.1) GO TO 501
   PRINT 11,ENERGY
11 FORMAT(1H0,///,64X,*MODEL       ENERGY= *E10.3/)
   PRINT 12
12 FORMAT(1H0,50X,*HEIGHT*,7X,*SPEED*,6X,*DIRECTION*,/,1H ,51X,*(M)*,
  S9X,*(M/S)*,8X,*(DEG)*)
   ERREU1=0
   ERREU2=0
   DO 600 I=1,K2,IPAS
   FF=SQRT(UG(I)**2+VG(I)**2)
   ANG=180./PI*ATAN(VC(I)/UC(I))
   DD=-DR-ANG
   ERREU1=ERREU1+SQRT(FF**2+VRI(I)**2-2*FF*VRI(I)*COS(PI*(DRI(I)-DD)/
  S180.))
   ERREU2=ERREU2+ABS(FF-VRI(I))
   DD=AMOD(DD,360.)
00 PRINT 13,ZZ(I),FF,DD
13 FORMAT(1H ,50X,F5,7X,F5.1,6X,F7)
   PRINT 505,ERREU1,ERREU2
05 FORMAT(50X,*ERREUR 1*,E12.3,/,50X,*ERREUR 2*,E12.3)
00 RETURN
01 PRINT 502
02 FORMAT(1H0,*PAS DE SOLUTION*)
   RETURN
   END
```

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```
      SUBROUTINE CALCUL(U1,U2,V1,V2,K2,PAS,UK2,VK2,NU)
      COMMON/PAPAM/TO     ,L2,M2,D2,GAMMAA ,Q,G,GAMMA,PI,LX,LY,LZ
      COMMON/RESULT/UC(4000),VC(4000),ZZ(4000)
      DIMENSION DENO(4000)
      REAL M2,L2
      UC(1)=U1 $ UC(2)=U2 $ VC(1)=V1 $ VC(2)=V2
      DO 600 J=3,K2
      A=G/(TO-GAMMA   *ZZ(J))*(M2+L2)*(GAMMA    -GAMMAA)
      DENO(J)=-L2*UC(J-1)**2+M2*VC(J-1)**2
      DENO(2)=DENO(3)
      A1     =A*Q*UC(J-1)/DENO(J)
      A2     =UC(J-1)*(D2*Q-2)+UC(J-2)
      B1      =A*Q*VC(J-1)/(-DENO(J))
      B2      =VC(J-1)*(D2*Q-2)+VC(J-2)
      UC(J)=A1-A2
      VC(J)=B1-B2
      IF (DENO(J)*DENO(J-1).LT.0.) GO TO 80
  600 CONTINUE
      UK2=UC(K2) $ VK2= VC(K2)
      GO TO 90
   80 NU=1
      RETURN
   90 NU=0
      RETURN
      END
```

```
      SUBROUTINE UV(DR,DIR,VEN,UR,VR)
      PI=3.14159
      B=(DR-DIR)*PI/180.
      UR=-VEN*COS(B)
      VR= VEN*SIN(B)
      RETURN
      END
```